INFLUENCE OF TEMPERATURE AND ALTITUDE ON THE EXPANSION OF COFFEE CROPS IN MATAS DE MINAS, BRAZIL

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Keywords:	

Coffea arabica
coffee cultivation
modeling
MaxEnt
SIG
species distribution

ABSTRACT

Coffee is among the most significant products in Brazil. Minas Gerais is the largest state producer of Arabica coffee. Coffee activity has excellent growth potential, which justifies the identification of new areas for expansion of the culture. This study aimed to determine factors that affect the spatial distribution of coffee plantations the most, as well as to identify areas with a greater aptitude for its expansion in the region of the Matas de Minas (63 municipalities). The MaxEnt software was used to elaborate a model capable of describing the area with the highest potential for estimating the probability of coffee adequacy. The elaboration of the model considered the records of occurrence, climatic and topographic variables of Matas de Minas, the second largest state producing region. The area under the curve (AUC), the omission rate and the Jackknife test were used for validation and analysis of the model. The model was accurate with an AUC of 0.816 and omission rate of 0.54% for the 'test'. It was identified that the potential distribution of coffee in Matas de Minas is determined by changes in the annual maximum temperature, although it did not generate a significant gain when omitted, accounting for a considerable loss in the model. However, the most influential variables on the delineation of distribution were, the altitude and the annual average temperature. The most favorable areas for expansion of coffee culture in the Matas de Minas were found in the vicinity of the region of Alto Caparaó.

Abbreviations used: A1 (altitude); A2 (maximum annual temperature); A3 (annual minimum temperature); BIO 1 (annual average temperature 1); BIO 4 (temperature seasonality), BIO 12 (annual precipitation); BIO 15 (precipitation seasonality); csv (comma-separated values); AUC (area under the curve).

Palavras-chave:	

Coffea arábica
cultivo de café
modelagem
MaxEnt
SIG
distribuição de espécies

INFLUÊNCIA DA TEMPERATURA E ALTITUDE NA EXPANSÃO DA CULTURA DO CAFÉ NAS MATAS DE MINAS, BRASIL

RESUMO

O café está entre os produtos mais significativos no Brasil, sendo Minas Gerais o maior produtor estadual de café arábica. A atividade cafeeira tem excelente potencial de crescimento, o que justifica a identificação de novas áreas para expansão da cultura. Este estudo teve como objetivo determinar os fatores que mais afetam a distribuição espacial dos cafezais, bem como identificar áreas com maior aptidão para sua expansão na região das Matas de Minas (63 municípios). O software MaxEnt foi utilizado para elaborar um modelo capaz de descrever a área com maior potencial para estimar a probabilidade de adequação do café. Considerou-se para a elaboração do modelo os registros de ocorrência, variáveis climáticas e topográficas de Matas de Minas, segunda maior região produtora do estado. A área sob a curva (area under the curve - AUC), a taxa de omissão e o teste de Jackknife foram usados para validação e análise do modelo. O modelo foi preciso com uma AUC de 0,816 e uma taxa de omissão de 0,54% para o 'teste'. Identificou-se que a distribuição potencial do café em Matas de Minas foi determinada por mudanças na temperatura máxima anual, embora não tenha gerado ganho significativo quando omitido, sendo responsável por uma perda considerável no modelo. No entanto, as variáveis mais influentes no delineamento da distribuição foram, respectivamente, a altitude e a temperatura média anual. As áreas mais favoráveis à expansão da cultura cafeeira nas Matas de Minas foram encontradas nas proximidades da região do Alto Caparaó.

INTRODUCTION

Currently, Brazil is the largest producer and exporter of coffee in the world. Its cultivation is mostly concentrated in the state of Minas Gerais, which accounts for half of the country's production, on average (CONAB, 2017).

In the State of Minas Gerais, the region of Matas de Minas is an important producer of specialty coffees (FERREIRA et al., 2016). This region is located in the east of the state, a region with wavy relief and mild temperatures, positive characteristsc for the coffee crop (ZAFAR et al., 2017). For this reason, studies related to the spatial distribution of Arabica coffee in the region are relevant for the identification of new areas with potential for expansion of the regional coffee park.

The generation of models that describe the potential distribution of a given species (such as coffee in this study) is a complicated process (SANTANA et al., 2008). This process relates observations of occurrence of species with a multivariate set of information of the analyzed area, such as the prevailing climatic conditions and local altitude, among others. It is worth remembering that for the modeling execution, the previous knowledge of the studied species is of paramount importance since the data that 'restrict the occurrence of the studied species' are those that define its dispersion potential. The multivariate techniques make it possible to evaluate the significance of the results and allow to use the information for analyzing the specific conditions (SANTOS et al., 2017).

In this context, this study sought to use the modeling technique to evaluate in the current scenario, new areas with higher potential for the expansion of the exploitation of this crop in the region of Matas de Minas. In addition, based on the relation between the points of occurrence, represented by coffee plantations and bioclimatic variables, to be able to identify the variables that most influence the modeling process of coffee cultivation in the region. In this study, the analysis was made purely with climatic data, not considering other factors such as the soil type, the face of exposure and the slope of the area, among others.

MATERIAL AND METHODS

The area of Matas de Minas has 63 municipalities, being identified in it, adopting the 'Datum SIRGAS 2000', and georeferenced 367 crops of *Coffea arabica*.

With the use of the ArcGis10.2 software, all data representing the most influential bioclimatic variables in Arabic coffee cultivation were converted from raster format to ASCII. The variables were: altitude (A1), maximum annual temperature (A2), minimum annual temperature (A3), annual average temperature (BIO 1), temperature seasonality (BIO 4), annual precipitation (BIO 12) and precipitation seasonality (BIO 15). The data were obtained on the WorldClim site (http://www.worldclim.org) in the raster format, with spatial resolution of 1 km.

The software 'MaxEnt 3.3.3k' was used, which is based on a multinomial logistic regression model and, according to ARANDA & LOBO (2011), stands out with great efficiency in the studies of species occurrence. All data referring to the location of coffee plantations were converted using the EXCEL spreadsheet to the 'csv' format (comma-separated values) that is required by the program.

The following were considered in MaxEnt: convergence threshold; maximum interaction; multiplier regularization; maximum number of background points; number of repetitions; the applied threshold rule and the replicated run type. The latter is denominated bootstrap, which is a 'resampling' technique used when few sample data are available and when multinomial regression models are considered, as it is the case of the present work. It was considered at random, 75% of the points for the 'training' of the model and 25% for the implementation of the 'test' for each repetition.

The final map was elaborated based on the average of the values found in the ten repetitions to reduce the overestimation of the result by the model, thus allowing the obtaining of the more accurate result.

MaxEnt generated a file in the 'HTML' format containing all the modeling results, among which, the following can be highlighted: the default rate, the area under the curve (AUC), the Jackknife test and the probability distribution map of occurrence of the species.

The validation was done based on AUC results and omission rates. The AUC results can be interpreted as the probability of the model to correctly classify the points of presence and absence of the species considered. For that, the values were classified according to the proposal presented by METZ (1986): 0.9 to 1.0 (excellent); 0.8 to 0.9 (good); 0.7 to 0.8 (mean); 0.6 to 0.7 (bad) and 0.5 to 0.6 (very poor). Therefore, AUC value 1.0 represents the perfect model while the value below 0.5 represents a randomly selected model.

The Jackknife test was applied to evaluate which variable had the most significant influence on the species distribution (ELITH,2011). In this test, the variable with a value close to '0' represents an unreliable prediction, and close to '1' represents information highly correlated to occurrences, that is, correct predictions (COELHO et al., 2016).

RESULTS AND DISCUSSION

The result obtained for the area under the curve (AUC), comprised below the 'training' lines - red, and 'test' - blue (which represent the composition of all lines generated as a result of the ten replicates of the model) (Figure 1). Figure 2 shows the result obtained for the omission rate. This parameter, as well as the AUC, is also used to validate the Arabica coffee distribution model for the Matas de Minas region.
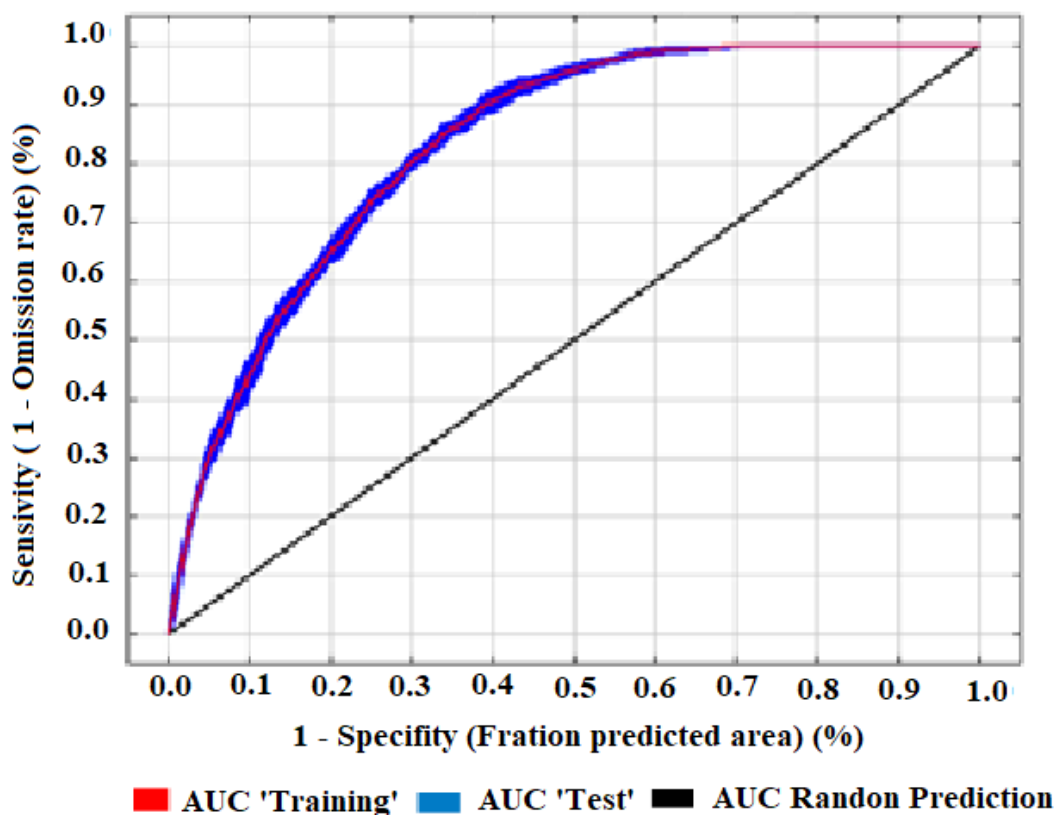

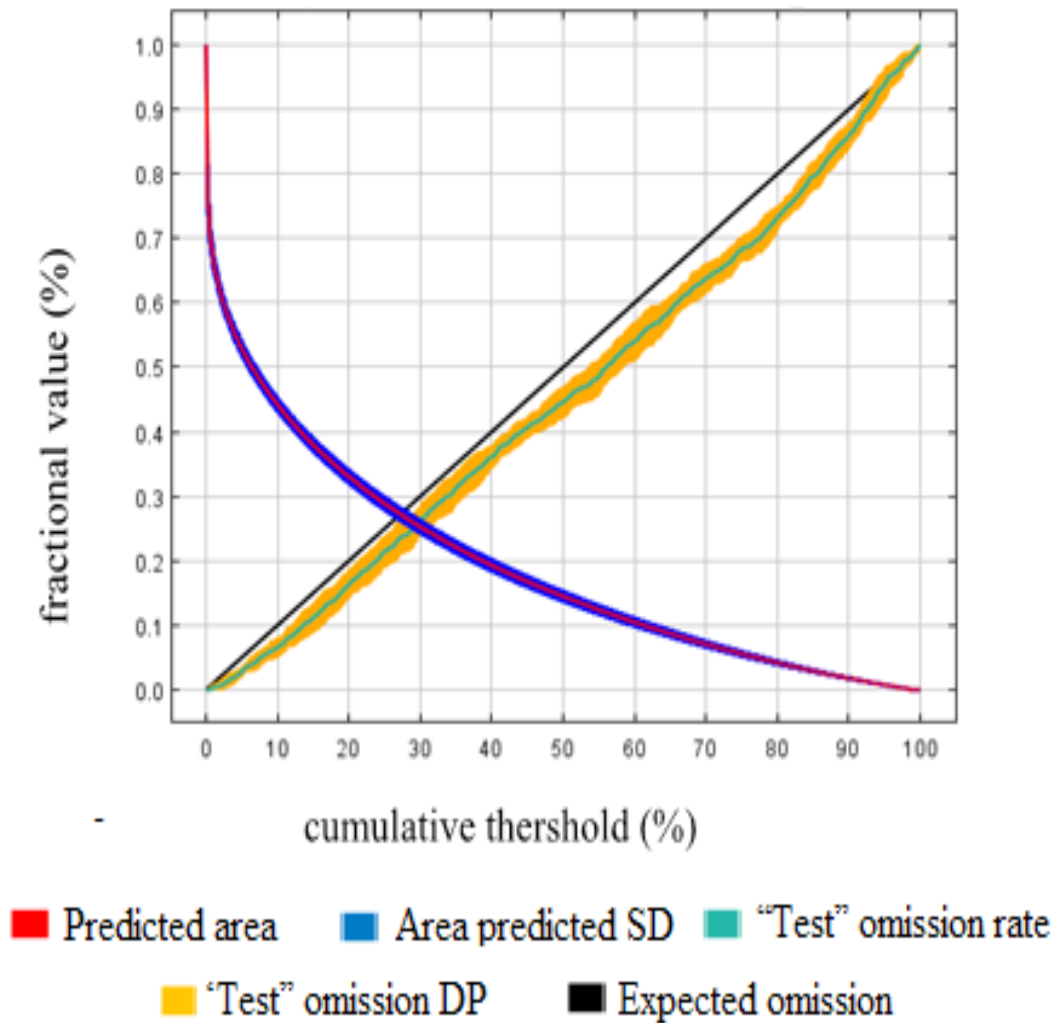**Figure 1.** Area under the curve considered for the 'training' and 'test' of the model.

Figure 2. Graph of the default rate and the predicted area in which the Standard Deviation is represented by SD.

The results of the Jackknife test can be observed when considering the 'training' (Figure 3a) and 'test' (Figure 3b) data. It can be seen in Table 1 the contribution percentage values of the variables only in the 'training' as such analysis is not processed in the 'test' of the model. These results make it possible to determine the influence of variables in the model.

The map with the identification of potential areas for the expansion of Arabica coffee in the Matas de Minas region is shown as a result of the MaxEnt modeling (Figure 4).

The values are given in percentages of the axis of the ordinates (sensitivity) and the abscissa (specificity) represents the probability that a particular pixel can be correctly classified as 'occurrence' and 'absence', respectively.

Both values represented by the 'training' line area and the 'test' area are larger than the under the 'random prediction' line (black line representing the value for the predictions made at random, that is, with the most significant fraction of false positives).

Therefore, it can be considered that the generated model stands out as a good predictor, since it presents a low fraction of false positive values. This fact can also be verified based on the mean values obtained, which are 0.832 (± 0.004) and 0.816 (± 0.02), for 'training' and 'test', respectively. Other studies using the Maxent algorithm also showed
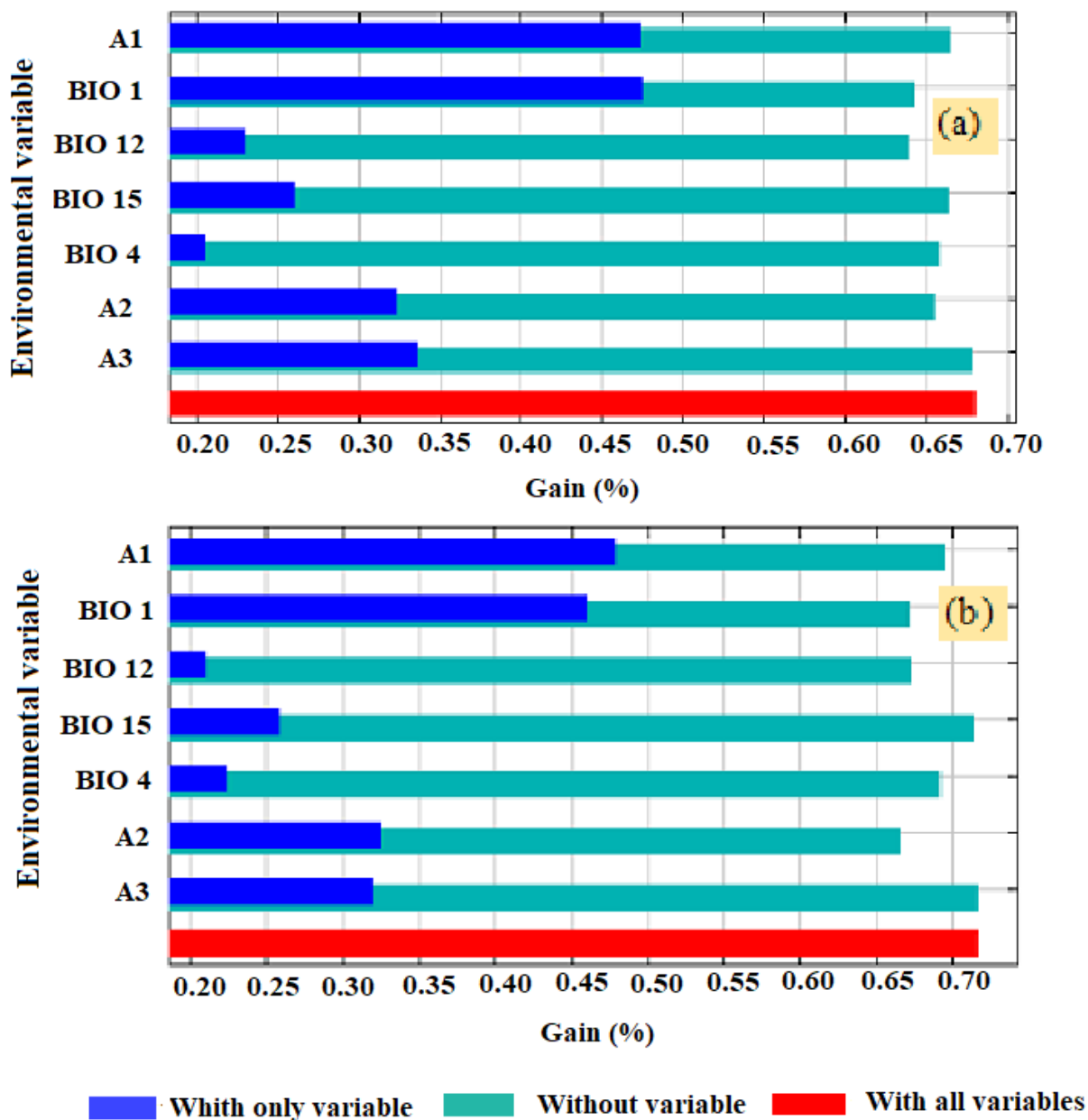
Figure 3. Jackknife test for 'training' (a) and for the 'test' (b).

Table 1. Contribution of the variables in the model from the 'training' data.

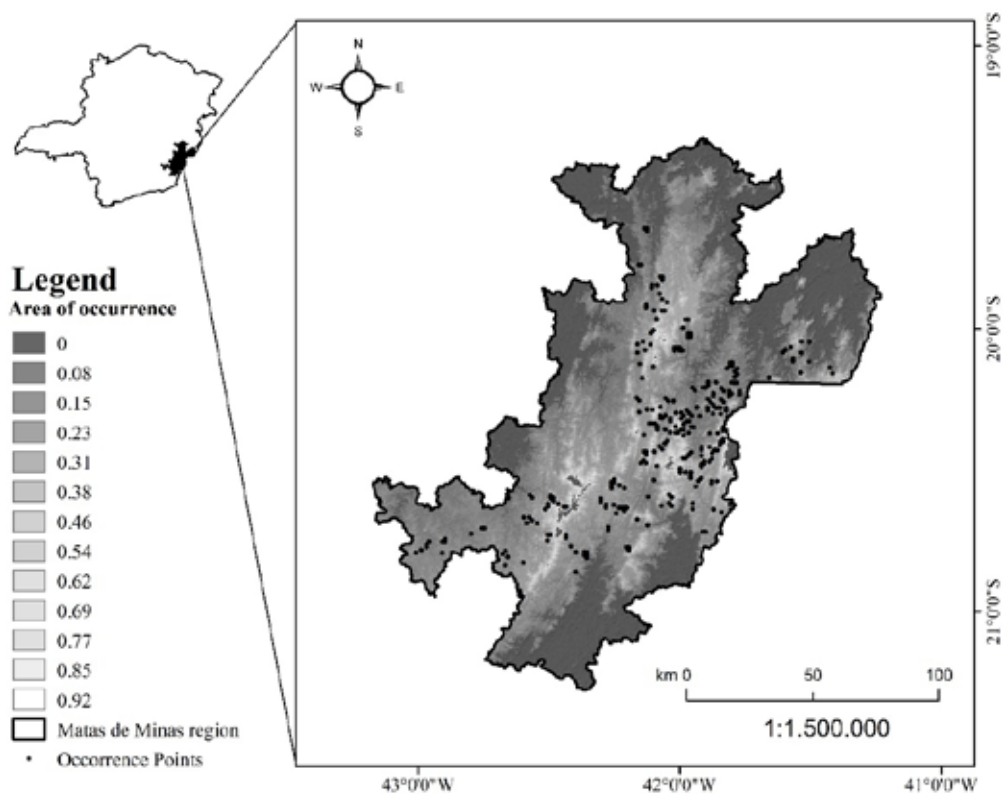| COD	Variables	Contributions (%)
A1	Altitude	52.3
BIO 15	Precipitation seasonality	17.4
BIO 1	Annual average temperature	13.7
BIO 4	Temperature seasonality	9.2
BIO 12	Annual precipitation	5.1
A2	Annual maximum temperature	1.8
A3	Annual minimum temperature	0.5

Figure 4. Map of the location of Matas de Minas, with emphasis in the area with the highest favorability to the expansion of Arabica coffee crops.

good accuracy, usually providing AUC values closer or greater than 0.9 (RABBIT et al., 2016).

It should be observed that the value obtained for AUC of the 'training' was higher than the value obtained for 'test', mainly because of the greater number of sampling points used in its analysis. It can be observed that for the standard deviation, despite using random data sets at each repetition, the values '0.004' and '0.02' found for 'training' and 'test', respectively, indicate good precision and accuracy of the model generated.

In Figure, 2 the observed closeness between the 'test' omission rate line (turquoise color - referring to the mean of the omission rate of the ten replicates of the model) and the expected omission rate line (black straight line - represents the absence of false positive values) indicates a right prediction of the model.

These results can also be verified based on the values obtained for omission rate and the predicted area, which were 0.54% (± 0.07) and 65.42% (± 0.45), respectively. Therefore, of the total of 65.42% of the predicted points as favorable to the

occurrence of coffee, 0.54% was considered by the model as false positives, thus, as a prediction error.

It can be observed in Table 1 that the variable A1 represents a gain by 52.3% in the model, that is, the coffee distribution is directly linked to altitude. This fact was already expected since the the crops installed in the region of the Matas de Minas are mostly at altitudes above 700 m.

According to Carmargo (2010), factors such as altitude and air temperature directly influence the productivity and quality of the grain, which justifies the fact that they are presented as essential variables in determining the distribution of Arabica coffee.

Similar results can be seen in Figure 3b, where altitude (A1) and annual average temperature (BIO 1) stand out as important factors in generating models, being individually responsible for 48 and 46%, respectively, of results presented by the 'test' model. Although the annual maximum temperature (A2) variable does not generate such a significant gain in relation to the others (about 33% - bar in blue) when removed from the model, it is

responsible for a considerable loss in the quality of the model. As a result, the variable A2 presents an essential contribution to the excellent result of MaxEnt modeling.

As for the gain of 0.7163 obtained when all variables are considered together (red bar in the Figure 3b), this result means that all the variables considered for designing the model are well represented, since the closer to the value of 1, the higher the contribution weight of the variable to the final MaxEnt result.

It can be seen in the Figure that 'warm colors' (values close to 1) represent the locations where the probability of implantation of new coffee plantations is more favorable, while "cold colors" (values near zero) represent the regions where the environmental and climatic conditions are unfavorable.

Based on geospatial distribution, it is possible to observe that coffee presents a greater implantation potential for the crops that are grown near the municipalities of Alto Caparaó, Alto Jequitibá, Caparaó, Espera Feliz, Martins Soares and Minhumirin. Therefore, complementary studies that take into account the soil characteristics of the region, among other characteristics, should be encouraged in order to increase the accuracy of the identification of the main areas for expansion of coffee production in the region.

CONCLUSIONS

- Altitude, Annual Average Temperature, and Annual Maximum Temperature are the variables that influenced the most the distribution of Arabica coffee species in the Matas de Minas region.

- The surroundings of the Alto Caparaó, Alto Jequitibá, Caparaó, Espera Feliz, Martins Soares and Minhumirin municipalities represent the area with the greatest significant potential for the expansion of Arabica coffee cultivation.

- The generated model presented good predictive capacity therefore, it is a useful instrument to guide political decision makers in coffee growing in Minas Gerais, as well as

the farmers themselves, where efforts should be invested to expand coffee plantations in the Matas de Minas region.

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Revista Engenharia na Agricultura